

## Hap punch: Wearable haptic device provides tactile feedback of the punch

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**Abstract:** This paper presents **HapPunch**, a novel wrist-worn haptic device designed to passively deliver punching sensations for augmented reality (AR) and virtual reality (VR) applications. The device provides tactile feedback through a simple, passive mechanism, where a movable mass drives to a knuckle flap via mechanical linkages. The motion of the flap is activated by the inertial force generated from the user's punch while providing realistic tactile feedback in virtual interactions. Experiments were conducted using four basic boxing punches—jab, cross, hook, and uppercut—to evaluate the system's performance. Contact sensors were used to measure the time interval between the completion of each punch and the corresponding tactile feedback. Results demonstrated that the device consistently delivered tactile feedback within a time range of **0.1 to 0.3 seconds**. Moreover, limitations and future works are discussing more in the research paper. the results highlight the potential of **HapPunch** as a practical and immersive haptic feedback solution for future VR applications.

**Keywords:** Wearable haptic device, Tactile feedback, Virtual reality, Mass moving, Gaming.

### 1. INTRODUCTION

Haptic devices are the one of the mediums to interact with the Virtual Reality (VR) environments. These devices are integrated with Virtual Environment (VE) to control and feel the stimuli. To enhance the immersion of VR researchers are developing different kinds of haptic devices such as handheld devices, wearable devices, haptic surfaces, etc. These devices are used for various applications such as gaming, rehabilitation, teleoperation, etc.

Wearable haptic devices are the devices which are fixed to the body of the users. Integrated with the sensor for motion tracking and give tactile or kinesthetic feedback using the actuators to enhance the immersion of VR. Moreover, it provides mobility, lightweight and portable facilities compared to other types of haptic devices[1]. Most commercial devices provide only tactile feedback while researchers are developing a wide variety of wearable haptic devices which also provide kinesthetic feedback also[2].

Recent advances in wearable haptic devices have enhanced immersion in virtual reality (VR) applications and especially sport-related games such as VR boxing. Several systems actively simulate the punch feel. A wearable system deliver Electrical Muscle Stimulation (EMS) to contracts the biceps to simulate a punch, with 78% of participants preferring this system and 81% reporting enhanced realism [3]. Additionally, a forearm-wearable multidimensional stretch display called Quad Stretch was introduced for diverse VR interactions such as boxing, shooting, and climbing. This lightweight device integrates eight skin stretch modules, inducing forces of 0.8 kgf with displacements of 8–11 mm at 73 mm/s [4]. Furthermore, developed a moisture-resistant soft actuator for VR boxing, providing tactile feedback at

three intensities with over 98% accuracy [5]. Moreover, a haptic pivot system simulating grasping and throwing forces achieved 87% accuracy in differentiating object weights in 100 g increments [2].

There has been limited research conducted on passive wearable haptic devices for sports training applications. Active haptic devices often face drawbacks such as the need for numerous sensors and actuators which are often expensive, the associated complexities in design and control and an increased bulk from battery. In the context of boxing and similar high-impact VR games, using such devices can lead to user fatigue due to their weight and size, and the complex attachments increase the risk of damage during vigorous movements. To address these limitations, we developed the HapPunch device — a lightweight, simple, and passively actuated wearable haptic system specifically designed to provide kinesthetic feedback of punching in alignment with user's movement. The concept of this device is shown in Fig.1 and will be explained in the next section.

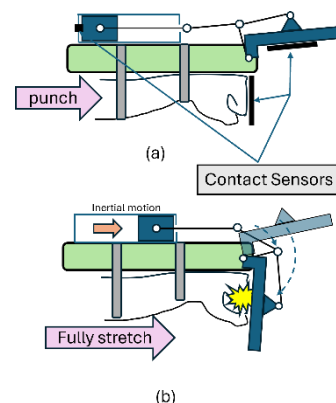


Fig. 1 Concept of Hap punch device. a – Flap opened position, b – Flap closed position.

\* Ovin Lakpura is the presenter of this paper.

This research hopes to contribute to a low-latency and realistic feeling of contact for the air-punching normally used in VR boxing game.

## 2. MECHANICAL DESIGN

The device primarily consists of three integrated components, as illustrated in Fig. 2 weight-moving tube, mechanical linkages, and a flapping part that provides tactile sensations and feedback to the user. The model is used to design the four-bar linkage utilized to operate the flap from the movement of mass. This is operating as a reverse crank slider. The mechanical linkages are designed using *MotionGen* software, followed by the complete machine design process carried out in *SolidWorks*. The prototype was subsequently manufactured through 3D printing. The device is secured to the user's hand using two adjustable belts, allowing for size customization.

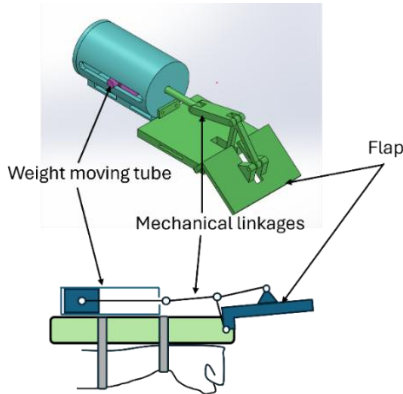


Fig. 2 Passive haptic (Hap punch) device

A movable weight of 200 g is integrated within the system, represented in purple inside the weight-moving tube as shown in Fig. 2. This component generates external forces on the mechanical linkage system due to inertia and gravity as the user moves their hand. When the user performs a forceful jab and the hand comes to a sudden stop, the movable weight continues its motion. As a result, it actuates the mechanical linkage, causing the flapping part to close, as illustrated in Fig. 1.

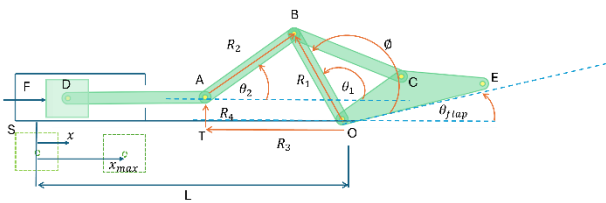


Fig. 3 Mechanism of the Hap Punch device

After the punch, the moving mass initially experiences a force  $F$  applied by the user's hand. Beyond this point, the only force acting on the mass is the negligible frictional force. As a result, mass  $D$  continues to move with a constant speed, maintaining the momentum gained from the user's hand speed. Since, initial hand position of the boxing vertically, mass  $D$  moves through the gravity to

the rear part of the cylinder (Fig. 3).

Table 1: Essential parameters

Parameters	Length(mm)
DA	83.0
AB	80.0
OB	47.5
BC	53.1
OE	65.0
AT	33.4
OC	56.3
L	165.0
$x_{max}$	80.0

Table 1 shows the length of the mechanical linkages shown in Fig. 3 and there's notation in the equations below. Let's find the displacement, velocity and the acceleration of the system analytically for the future modelling purpose.

Complete mechanism further can be simplified to the Slider crank mechanism as shown in figure 4. Here,  $R_1, R_2, R_3,$  and  $R_4$  represent the vector loop[6].

Therefore,

$$R_1 - R_2 - R_4 - R_3 = 0$$

According to the reference[6],

$$r_3 = r_2 \cos\left(\sin^{-1}\left(\frac{r_1 \sin(\theta_1) - r_4}{r_2}\right)\right) - r_1 \cos(\theta_1) \quad (1)$$

$$\theta_1 = \theta_{flap} + \phi \quad (2)$$

Where,  $OB = r_1, AB = r_2, OT = r_3,$  and  $TA = r_4$ .

Therefore, we can obtain, function of the displacement ( $x \geq 10\text{mm}$ ) of the inertial mass and angle ( $\theta_{flap}$ ) of the OE link.

$$x = L - DA - r_3$$

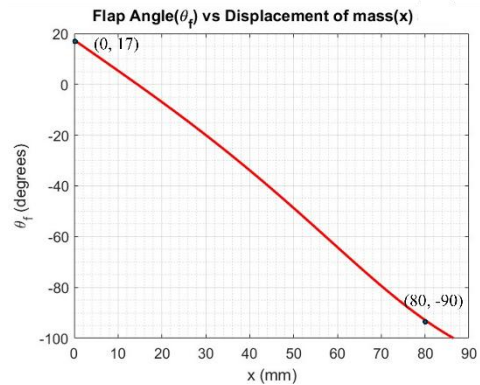


Fig. 4 Translational displacement of the mass and angular displacement of the flap

The graph illustrated in fig 4 represents the variation of the angular displacement of the flap against translational displacement of the moving mass. The angular displacement shows almost -90 degrees while mass moving around 8 cm. Initial position of the flap shows 17 degrees. The mechanism is designed so that the flap will stop immediately as soon as stroke of the arm is completed.

In boxing, users typically position their hands vertically, delivering punches with force. Initially, the movable mass remains at the rear end of the moving tube because of gravity. As the punch is executed, the mass gains kinetic energy and continues to move even after the punch is halted, in the absence of any external force. The momentum of the mass then acts on the mechanical system, generating a force that triggers the flap mechanism to close immediately. Then, the device is reset after the forearm moves back to initial position as illustrated in Fig. 5.

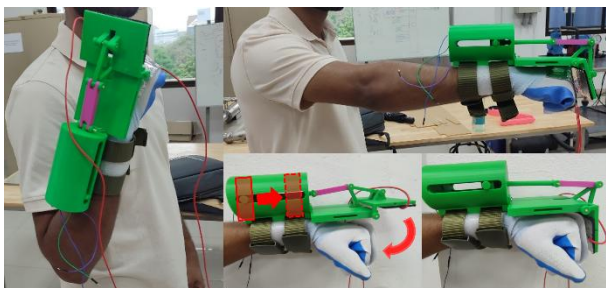


Fig. 5 Arrangement of the device in different postures

To measure the time interval between the punch and the resulting tactile feedback, two sensors are incorporated as shown in Fig 1: contact sensor located between the flapping part and the user's hand and sensor at rear part of weight moving tube (Fig 2) is a terminal switch, while the contact sensor is fabricated using two layers of aluminum foil. When the user's hand contacts the flapping part, the contact sensor generates a digital signal, which is transmitted to the microcontroller for processing.

When the user's hand is in the initial position, the movable mass remains in contact with the terminal switch located at rear side of the weight moving tube. As the mass begins to move towards the front, the terminal switch sends a signal to the microcontroller to initiate time recording. This time measurement is halted when the contact sensor in the flapping part detects contact and sends a corresponding digital signal to the controller, as illustrated in Fig. 1. An ESP32 microcontroller is employed for signal processing and time measurement in this system.

### 3. RESULTS AND DISCUSSION

Experiments were conducted to evaluate the performance and reaction time of the Hap Punch device within virtual reality (VR) environments. The assessments were carried out in a free movement setting that allowed participants

to perform basic boxing punches, including the Jab, Cross, Hook, and Uppercut. For each punch type, the time interval between the execution of the punch and the activation of the flapping component delivering the tactile sensation was measured. Additionally, the consistency of the device's performance across the different punch types was examined.

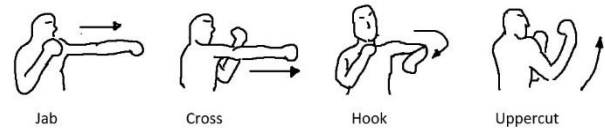


Fig. 6 Basic punches of the boxing

According to the results obtained, the device required only a minimal amount of time to deliver tactile feedback to the user's hand. Additionally, the reaction time varied between users due to differences in applied force and hand speed. In this study, the same type of punch was performed five times, and the corresponding results were recorded, as presented in Fig. 5.

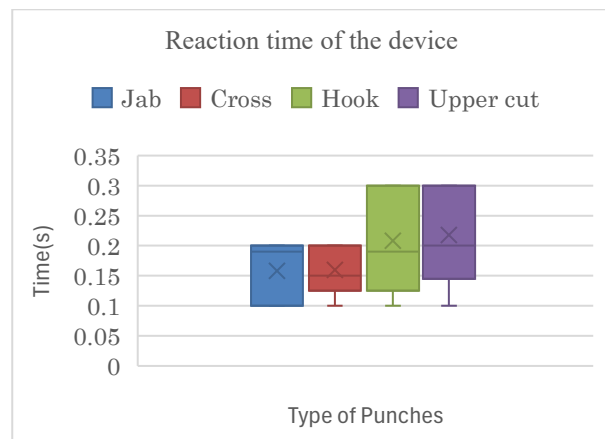


Fig. 7 Graph of the time gap between punch and tactile feedback vs Number of Tests

Fig. 7 illustrates the reaction time of the device during the execution of basic boxing punches. Each punch type was tested five times to assess consistency. The jab and cross punches exhibited a median reaction time of approximately 0.15 seconds, whereas the hook and uppercut demonstrated longer median reaction times of around 0.25 seconds, accompanied by a wider range of deviations. Overall, the reaction time of the device consistently remained within the range of 0.1 to 0.3 seconds across all punch types.

Table 2: Feedback latency of the active haptic devices

Haptic device	Feedback latency
Quad stretch[4]	0.233 ms
Soft pneumatic actuator[7]	10 ms
RML- Glove[8]	30 ms

Table 2 presents the feedback latency of active haptic devices. According to these results, the reaction time of the Hap Punch device is comparatively high. However,

considering that the average human tactile reaction time is approximately 0.05 - 0.3 seconds[9], the device demonstrates acceptable performance for the Jab and Cross punches. In contrast, the reaction times for the Uppercut and Hook should be slightly reduced to improve responsiveness. Furthermore, there is limited research that has been conducted on sports training applications using passive haptic devices.

## 5. CONCLUSION

In this paper, a novel haptic device designed for applications in augmented reality (AR) and virtual reality (VR) scenarios has been introduced. This device provides both tactile and kinesthetic feedback by dynamically creating and removing a haptic proxy within the user's fist. One of the key advantages of the proposed system is that it does not require a battery pack to actuate the mechanisms, nor does it need to be directly linked to a virtual environment to deliver stimuli. Experiments were conducted by the authors to measure the time interval between the actual punch and the resulting tactile feedback, using sensors integrated into the device. The measured reaction time ranged from 0.1 to 0.3 seconds during basic boxing punches. Nevertheless, based on the obtained results and observed usability, it can be concluded that this device holds promising potential for future haptic feedback applications.

## 5. LIMITATIONS AND FUTURE WORKS

While the device consistently provides tactile feedback with every punch, it is not suitable for all interaction scenarios. For instance, when a user performs a casual punch without contacting virtual objects within the environment, delivering tactile feedback in such cases may be unnecessary and could negatively affect immersion. To enhance the overall haptic experience in virtual reality applications, it is important to improve the quality of the contacting surface, thereby increasing the realism and immersion of the resulting tactile sensations. Additionally, incorporating feedback sensing mechanisms capable of synchronizing with VR games is recommended to ensure context-appropriate feedback delivery.

Furthermore, certain limitations are present when rendering tactile feedback for uppercut movements. As an uppercut is executed with the hand oriented vertically, the flapping mechanism provides feedback only momentarily. After the applied force, the movable weight causes the flapping component to rapidly return to its initial position, restricting the duration of tactile sensation experienced by the user. Other limitations of the current prototype include a short continuous contact time with the tactile surface and the possibility of unintended actuation.

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